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Koninklijke Philips Electronics N.V.  
Groenewoudseweg 1  
5621 BA Eindhoven  
PAYS-BAS

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Optical disc drive apparatus, and method for measuring tilt of an optical disc

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## Optical disc drive apparatus, and method for measuring tilt of an optical disc

The present invention relates in general to a disc drive apparatus for writing/reading information into/from an optical storage disc, wherein the disc is rotated and a write/read head is moved radially with respect to the rotating disc. The present invention is applicable in the case of optical as well as magneto-optical disc systems. Hereinafter, the  
5 wording "optical disc drive" will be used, but it is to be understood that this wording is intended to also cover magneto-optical disc systems.

As is commonly known, an optical storage disc comprises at least one track,  
10 either in the form of a continuous spiral or in the form of multiple concentric circles, of storage space where information may be stored in the form of a data pattern. Optical discs may be read-only type, where information is recorded during manufacturing, which information can only be read by a user. The optical storage disc may also be a writable type, where information may be stored by a user.

15 For writing information in the storage space of the optical storage disc, or for reading information from the disc, an optical disc drive comprises, on the one hand, rotating means for receiving and rotating an optical disc, and on the other hand optical means for generating an optical beam, typically a laser beam, and for scanning the storage track with said laser beam. Since the technology of optical discs in general, the way in which  
20 information can be stored in an optical disc, and the way in which optical data can be read from an optical disc, is commonly known, it is not necessary here to describe this technology in more detail.

For rotating the optical disc, an optical disc drive typically comprises a motor, which drives a hub engaging a central portion of the optical disc. Usually, the motor is  
25 implemented as a spindle motor, and the motor-driven hub may be arranged directly on the spindle axle of the motor.

For optically scanning the rotating disc, an optical disc drive comprises a light beam generator device (typically a laser diode), an objective lens for focussing the light beam

in a focal spot on the disc, and an optical detector for receiving the reflected light reflected from the disc and for generating an electrical detector output signal.

During operation, the light beam should remain focussed on the disc. To this end, the objective lens is arranged axially displaceable, and the optical disc drive comprises focal actuator means for controlling the axial position of the objective lens. Further, the focal spot should remain aligned with a track or should be capable of being positioned with respect to a new track. To this end, at least the objective lens is mounted radially displaceable, and the optical disc drive comprises radial actuator means for controlling the radial position of the objective lens.

In many disc drives, the orientation of the objective lens is fixed, i.e. its axis is directed parallel to the rotation axis of the disc. In some disc drives, the objective lens is pivotably mounted, such that its axis can make an angle with the rotation axis of the disc.

For any reason, it may be that the optical disc suffers from tilt. Tilt of the optical disc can be defined as a situation where the storage layer of the optical disc, at the location of the focal spot, is not exactly perpendicular to the optical axis. Tilt can be caused by the optical disc being tilted as a whole, but is usually caused by the optical disc being warped, and as a consequence the amount of tilt depends on the location on disc. Especially systems which have a relatively large numerical aperture (NA) are sensitive to disc tilt. Therefore, tilt compensation mechanisms have been developed. Typically, in a disc drive apparatus having tilt compensation, at least the objective lens is mounted pivotably, and the optical disc drive comprises tilt actuator means for controlling the tilt position of the objective lens. Alternatively, it is possible that the orientation of the disc itself is corrected. Other types of controllable tilt correction mechanisms are possible, too.

Thus, in general, there is a demand for a method to measure tilt.

It is possible to measure the tilt with a separate tilt sensor. However, such solution would involve additional hardware and increased costs.

It has already been proposed in prior art to process an electrical output signal from the optical detector in order to obtain a tilt measuring signal indicating the tilt angle. Based on such a tilt measuring signal, a tilt controller can control the tilt actuator means in such a way that the tilt angle is reduced or even made zero.

For instance, EP-0.986.053 discloses a tilt control method which is based on processing a radial error signal indicated as the radial push-pull signal.

The present invention relates specifically to a disc drive apparatus where a first light beam is used for the writing/reading operation while a second light beam is used for tilt measurement. In the following, the second beam will also be referred to as tilt beam and the first beam will also be referred to as data beam. In a preferred embodiment, the tilt beam  
5 has a colour differing from the colour of the data beam, while further the tilt beam is substantially out-of-focus whereas the data beam is substantially maintained in-focus by the focus actuator.

It is noted that the present invention is particularly useful for a disc drive apparatus capable of handling two or more different disc types, such as for instance CD,  
10 DVD, Blu-Ray, with two or more different laser beams, and the present invention will be specifically explained hereinafter for such type of disc drive apparatus, which will also be referred to as combi-drive. However, it is to be noted that it is not intended to restrict the scope of the present invention to such combi-drives, because the gist of the invention can also be applied to CD-only drives or DVD-only drives, for instance, although this would require  
15 the installation of a second optical system.

As will be known to a person skilled in the art, the laser light used for DVD has a shorter wavelength than the laser light used for CD. When a combi-drive is in a CD-playing mode, the tilt beam will be the DVD beam, hence the tilt beam has a shorter wavelength than the data beam. When, on the other hand, the combi-drive is in a DVD-  
20 playing mode, the tilt beam will be the CD beam, hence the tilt beam has a longer wavelength than the data beam.

In a combi-drive, the tilt beam and the data beam are received by the same optical detector. Therefore, in order to derive an electrical tilt-indicative signal component from the electrical output signal from the optical detector, it is necessary to separate signal  
25 components caused by the data beam and signal components caused by the tilt beam. JP-2000.076.679-A discloses a combi-drive where, for this purpose, the tilt beam is modulated with a predetermined modulation frequency, resulting in an electrical tilt-indicative signal component having the same frequency. A band-pass filter is used to derive this signal component, which is further processed for measuring tilt. This technique  
30 has some disadvantages.

On the one hand, this technique requires the use of at least a beam modulator, a bandpass filter, and a peak detector, which adds to the complexity and cost of the apparatus.

On the other hand, the tilt beam causes an electrical signal having modulation as well as a DC component, which may affect error detection based on the read signal output.

The amount of influence is not constant but depends on tilt direction and magnitude, therefore the required compensation of this effect is difficult.

Further, the continuous use of the tilt beam adds to the power dissipation of the apparatus.

5 It is a general objective of the present invention to overcome these drawbacks.

More particularly, it is an objective of the present invention to provide a tilt measuring method which can be implemented with less expense, and which dissipates less power.

10 Further, it is an objective of the present invention to provide a tilt measuring method which has less influence on the normal signal processing, or at least an influence which is more easily compensated.

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#### SUMMARY OF THE INVENTION

15 According to an important aspect of the present invention, the tilt beam is alternately switched ON and OFF. Tilt measurements are performed during the time periods during which the tilt beam is ON. These ON time periods can be relatively short, such as to keep any disturbance of the servo error signal minimal.

20 According to a further important aspect of the present invention, the error signal is ignored during said ON time periods, and the control signals for the lens actuators are frozen during said ON time periods, so that any possible influence of the tilt beam on the error signal do not actually affect actuator control. In this regard, the duration of said ON time periods is selected to be shorter than a relevant time scale of expected changes of the error signal.

25 According to a still further important aspect of the present invention, the intensity profile of the tilt beam as a function of time is chosen to be a cosine shape, in order to prevent spectral components in the data frequency range.

30 These and other aspects, features and advantages of the present invention will be further explained by the following description with reference to the drawings, in which same reference numerals indicate same or similar parts, and in which:

Figure 1A schematically illustrates an optical disc drive;

Figure 1B is a block diagram illustrating schematically an optical detector connected to a signal processor;

Figure 2 is a graph illustrating a tracking error signal as a function of radial lens position;

5 Figure 3 is a timing diagram illustrating the operation of a disc drive in accordance with the present invention;

Figure 4 is a block diagram schematically illustrating components of a preferred embodiment of a control circuit.

10 Figure 1A schematically illustrates an optical disc drive apparatus 1, suitable for storing information on or reading information from an optical disc 2, typically a DVD or a CD. For rotating the disc 2, the disc drive apparatus 1 comprises a motor 4 fixed to a frame (not shown for sake of simplicity), defining a rotation axis 5. For receiving and holding the  
15 disc 2, the disc drive apparatus 1 may comprise a turntable or clamping hub 6, which in the case of a spindle motor 4 is mounted on the spindle axle 7 of the motor 4.

The disc drive apparatus 1 further comprises an optical system 30 for scanning tracks (not shown) of the disc 2 by an optical beam. More specifically, in the exemplary arrangement illustrated in figure 1A, the optical system 30 comprises a first light beam  
20 generating means 31 and a second light beam generating means 41, each typically a laser such as a laser diode, each arranged to generate a first light beam 32 and a second light beam 42, respectively. In the following, different sections of the optical path of a light beam 32, 42 will be indicated by a character a, b, c, etc added to the reference numeral 32, 42, respectively.

25 The first laser 31 and the second laser 41 are different types of laser in that their respective laser beams 32, 42 have a different wavelength. For instance, a laser beam suitable for handling a CD has a wavelength in the order of about 780 nm, while a laser beam suitable for handling a DVD has a wavelength in the order of about 660 nm. The disc drive apparatus 1 may be designed for handling only one type of disc, i.e. either CD or DVD for  
30 example. In that case, the first laser beam 32 will have the wavelength mentioned for use with CD or DVD, respectively, while the second laser beam 42 is an auxiliary laser beam which may have, in principle, any suitable wavelength differing sufficiently from the first laser beam wavelength. In the case of a combi-drive, the disc drive apparatus 1 is designed for handling two or more types of disc, i.e. CD as well as DVD for example. In that case, the

first laser beam 32 will have the wavelength mentioned for use with CD or DVD, respectively, while the second laser beam 42 will have the wavelength mentioned for use with DVD or CD, respectively. For implementing or explaining the present invention, it does not matter whether the first laser beam 32 is a CD-type beam while the second laser beam 42 is a DVD-type beam, or the opposite.

The first light beam 32 passes a first beam splitter 43, a second beam splitter 33 and an objective lens 34 to reach (beam 32b) the disc 2. The beam splitters are schematically depicted as cubes, but may have other implementations. The first light beam 32b reflects from the disc 2 (reflected first light beam 32c) and passes the objective lens 34 and the second beam splitter 33 (beam 32d) to reach an optical detector 35.

The second light beam 42 is reflected by a mirror 44, passes the first beam splitter 43, and then follows an optical path comparable with the optical path of the first light beam 32, indicated by reference numerals 42b, 42c, 42d.

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The objective lens 34 is designed to focus one of the two light beams 32b, 42b in a focal spot F on a recording layer (not shown for sake of simplicity) of the disc 2, which spot F normally is circular. In the case of a disc drive apparatus for either CD or DVD only, the first beam 32 is focussed while the auxiliary second beam is out of focus. In the case of a combi-drive, the CD-type beam is focussed when a CD is being handled, in which case the DVD-type beam is out of focus, or the DVD-type beam is focussed when a DVD is being handled, in which case the CD-type beam is out of focus. For explaining the present invention, it does not matter which case is present. Therefore, for sake of explanation, it will be assumed in the following that the first beam 32 is in focus while the second beam 42 is out of focus. The first beam 32 will be indicated as data beam while the second beam will be indicated as tilt beam.

25

The disc drive apparatus 1 further comprises an actuator system 50, which comprises a radial actuator 51 for radially displacing the objective lens 34 with respect to the disc 2. Since radial actuators are known per se, while the present invention does not relate to the design and functioning of such radial actuator, it is not necessary here to discuss the design and functioning of a radial actuator in great detail.

For achieving and maintaining a correct focusing, exactly on the desired location of the disc 2, said objective lens 34 is mounted axially displaceable, while further the actuator system 50 also comprises a focal actuator 52 arranged for axially displacing the objective lens 34 with respect to the disc 2. Since axial actuators are known per se, while



further the design and operation of such axial actuator is no subject of the present invention, it is not necessary here to discuss the design and operation of such focal actuator in great detail.

For the purpose of tilt compensation, said objective lens is mounted such as to  
5 be pivotable about a pivot axis (not shown) which preferably coincides with the optical centre of the objective lens 34. Further, the actuator system 50 also comprises a pivot actuator 53, also indicated as tilt actuator, arranged for pivoting the objective lens 34 with respect to the disc 2.

It is noted that means for supporting the objective lens with respect to an  
10 apparatus frame, and means for axially and radially displacing the objective lens, are generally known per se. Since the design and operation of such supporting and displacing means are no subject of the present invention, it is not necessary here to discuss their design and operation in great detail. The same applies to means for pivoting the objective lens.

It is further noted that the radial actuator 51, focal actuator 52, and pivot  
15 actuator 53 may be implemented as one integrated 3D-actuator.

The disc drive apparatus 1 further comprises a control circuit 90 having a first  
output 92 connected to a control input of the motor 4, having a second output 93 coupled to a  
control input of the radial actuator 51, having a third output 94 coupled to a control input of  
the focal actuator 52, having a fourth output 95 coupled to a control input of the pivot  
20 actuator 53, and having a fifth output 96 coupled to a control input of the second laser 41.  
The control circuit 90 is designed to generate at its first output 92 a control signal  $S_{CM}$  for  
controlling the motor 4, to generate at its second control output 93 a control signal  $S_{CR}$  for  
controlling the radial actuator 51, to generate at its third output 94 a control signal  $S_{CF}$  for  
controlling the focal actuator 52, to generate at its fourth output 95 a control signal  $S_{CT}$  for  
25 controlling the pivot actuator 53 and to generate at its fifth output 96 a control signal  $S_{L2}$  for  
controlling the second laser 41.

The control circuit 90 further has a read signal input 91 for receiving a read  
signal  $S_R$  from the optical detector 35.

Figure 1B illustrates that the optical detector 35 comprises a plurality of  
30 detector segments, in this case four detector segments 35a, 35b, 35c, 35d, capable of  
providing individual detector signals A, B, C, D, respectively, indicating the amount of light  
incident on each of the four detector quadrants, respectively. A centre line 36, separating the  
first and fourth segments 35a and 35d from the second and third segments 35b and 35c, has a

direction corresponding to the track direction. Since such four-quadrant detector is commonly known per se, it is not necessary here to give a more detailed description of its design and functioning.

Figure 1B also illustrates that the read signal input 91 of the control circuit 90 actually comprises four inputs 91a, 91b, 91c, 91d for receiving said individual detector signals A, B, C, D, respectively. The control circuit 90 is designed to process said individual detector signals A, B, C, D, in order to derive data and control information therefrom, as will be clear to a person skilled in the art. For instance, a data signal  $S_D$  can be obtained by summation of all individual detector signals A, B, C, D according to

$$S_D = A + B + C + D \quad (1)$$

Further, a push-pull tracking error signal  $S_{TE}$  can be obtained by summation of the signals A and D from all individual detector segments 35a and 35d on one side of the centre line 36, ~~summation of the signals B and C from all individual detector segments 35b and 35c on the~~ other side of the centre line 36, and taking the difference of these two summations, according

to

$$S_{TE} = (A + D) - (B + C) \quad (2a)$$

Further, assuming that a cylindrical lens (not shown in the figure for sake of simplicity) is placed in front of the optical detector 35, a focal error signal  $S_{FE}$  can be obtained by summation of the signals A and C from one pair of individual detector segments 35a and 35c diagonally opposite to each other, summation of the signals B and D from the other pair of individual detector segments 35b and 35d diagonally opposite to each other, and taking the difference of these two summations, according to

$$S_{FE} = (A + C) - (B + D) \quad (3a)$$

In order to compensate light intensity variations of the beam as a whole, these error signals can be normalised by division by the data signal to obtain normalised tracking and focal error signals RES and FES, respectively, according to

$$RES = S_{TE} / S_D$$

(2b)

$$FES = S_{FE} / S_D$$

(3b)

The above formulas are basically correct for the data beam individually as well as for the tilt beam individually. However, in the case of non-zero disc tilt, the reflected light beams are subject to deflections, the deflection of the tilt beam differing from the deflection of the data beam. As a result, a light intensity pattern caused by the tilt beam on the detector 35 (also indicated as detector tilt spot) will be shifted with respect to a light intensity pattern caused by the data beam on the detector 35 (also indicated as detector data spot). This translates to a DC shift of the normalised tracking error signal RES, as illustrated in figure 2.

Figure 2 is a graph illustrating the normalised tracking error signal RES as a function of radial position of the lens 34, for a situation where both the data beam 32 and the tilt beam 42 are ON. The horizontal axis indicates track numbers; the vertical axis indicates signal magnitude in arbitrary units. The solid curve 61b shows the normalised tracking error signal RES in a case without radial tilt of the disc 2: it can be seen that the DC level of this signal is now equal to zero. The dashed and dotted lines 62 and 63 show the same normalised tracking error signal RES for a case where the disc 2 has positive and negative radial tilt (depending on the sign of the tilt angle), respectively: the DC level of this signal has now been shifted to a negative and a positive value, respectively.

The amount of this DC shift is a good measure for the amount of disc tilt (i.e. tilt angle). Thus, a tilt angle  $\theta$  can be calculated as

$$\theta = \text{DC}[\text{RES}(\text{T}+\text{D})] - \text{DC}[\text{RES}(\text{D})] \quad (4)$$

wherein:  $\text{DC}[x]$  indicates the DC level of a signal  $x$ ;  
 $\text{RES}(\text{D})$  indicates the normalised tracking error signal RES for a case with only the data beam ON;

$\text{RES}(\text{T}+\text{D})$  indicates the normalised tracking error signal RES for a case with both the data beam and the tilt beam being switched ON.

The illustrative figure 2 relates to a situation of track crossings for a case where a tracking servo loop is open. During normal disc drive operation, however, the tracking servo loop is closed in order to have the focal spot F stay on track, so that the radial actuator 51 is controlled to keep the normalised tracking error signal RES equal to zero. Consequently, in view of the shifted DC level of RES, the focal spot F is actually displaced with respect to the centre of the track being followed.

Figure 3 is a timing diagram illustrating the operation of the disc drive 1 in accordance with the present invention. Curve 71 represents the operation of the data beam 32, which is constantly switched ON. Curve 72 represents the operation of the tilt beam 42.

Normally, the tilt beam 42 is switched OFF, but at regular intervals the tilt beam 42 is briefly switched ON. In figure 3, the tilt beam is switched ON at times  $t_1$  and  $t_3$  whereas the tilt beam is switched OFF at times  $t_2$  and  $t_4$ .  $T_{ON}$  indicates a time period during which the tilt beam 42 is ON, having a duration  $\tau_{ON} = t_2 - t_1$ ; this time period will be indicated as tilt measuring phase.  $T_{OFF}$  indicates a time period during which the tilt beam 42 is OFF, having a duration  $\tau_{OFF} = t_3 - t_2$ ; this time period will be indicated as normal phase.

Curve 73 illustrates the normalised tracking error signal RES in a closed radial servo loop situation, while an operational mode of the control circuit 90 is illustrated at 74. During the normal phase  $T_{OFF}$ , the control circuit 90 uses the normalised tracking error signal RES as calculated from the optical detector 35 output signal  $S_R$  for controlling the radial actuator 51, as normal, indicated by  $S_R$  in figure 3.

At the times  $t_1$  and  $t_3$ , the control circuit 90 stores the current values of the signals  $S_D$ , RES and FES in a memory 97, after which the control circuit 90 switches the second laser 41 to its ON state. The values of the signals  $S_D$ , RES and FES thus stored, measured during the normal phase  $T_{OFF}$ , will be indicated as  $S_D(OFF)$ , RES(OFF) and FES(OFF), respectively.

During the tilt measuring phase  $T_{ON}$ , the control circuit 90 generates its actuator control signals  $S_{CR}$ ,  $S_{CF}$  and  $S_{CT}$  for the radial actuator 51, the focus actuator 52 and the pivot actuator 53, respectively, on the basis of the values of the signals  $S_D(OFF)$ , RES(OFF) and FES(OFF) read from memory 97, indicated by M in figure 3.

At the times  $t_2$  and  $t_4$ , the control circuit 90 switches the second laser 41 to its OFF state, after which the control circuit 90 returns to normal operation ( $S_R$ ).

In order to measure tilt, the control circuit 90 also measures a value of the tracking error signal RES from the optical detector 35 output signal  $S_R$  during the tilt measuring phase  $T_{ON}$ . This measured value may be one sample, for instance taken at approximately time  $t_1 + 0.5\tau_{ON}$ , or an average of multiple samples taken during the tilt measuring phase  $T_{ON}$ . This measured value will be indicated as RES(ON). This measured value RES(ON) may be processed immediately, or also stored in memory 97.

The control circuit 90 is now able to derive a tilt-indicating signal  $S_{TILT}$  indicative of the disc tilt angle  $\theta$  on the basis of RES(OFF) and RES(ON). For instance, the tilt-indicating signal  $S_{TILT}$  may be calculated as

$$S_{TILT} = RES(ON) - RES(OFF) \quad (5)$$

Alternatively, it is also possible that the control circuit 90 measures the value of the tracking error signal RES shortly after termination of the tilt measuring phase  $T_{ON}$ , this measured value being indicated as RES'(OFF). Then, the control circuit 90 is able to derive a tilt-indicating signal  $S_{TILT}$  on the basis of RES'(OFF) and RES(ON). For instance, the tilt-indicating signal  $S_{TILT}$  may be calculated as

$$S_{TILT} = RES(ON) - RES'(OFF) \quad (6)$$

Preferably, the control circuit 90 is designed to measure RES(OFF) at time  $t_1$  (or shortly before) and to also measure RES'(OFF) at time  $t_2$  (or shortly after), and to calculate the tilt-indicating signal  $S_{TILT}$  as

$$S_{TILT} = RES(ON) - (RES(OFF) + RES'(OFF))/2 \quad (7)$$

Further, the control circuit 90 is designed to generate a control signal  $S_{CT}$  for the pivot actuator 53 such that the tilt-indicating signal  $S_{TILT}$  decreases, ideally becoming zero, indicating that the pivot actuator 53 has obtained a position well-matched to the disc tilt.

Experiments have been performed at a DVD disc rotating at a frequency of approximately 4.7 Hz. These experiments have shown that it is possible to have a duration  $\tau_{ON}$  of the tilt measuring phase  $T_{ON}$  of 150  $\mu s$  without affecting the data readout or the stability of the radial servo loop. Further, no significant increase in the jitter has been observed in these experiments. This means that the chance that the optical pickup deviates from track during a period of 150  $\mu s$  may be ignored. On the other hand, this period is long enough for obtaining adequate measuring samples from the tilt beam.

Each tilt measuring phase  $T_{ON}$  corresponds, in fact, with a tilt measurement at substantially one location on disc. In the case of a disc rotation at 4.7 Hz, a tilt measuring duration  $\tau_{ON}$  of 150  $\mu s$  corresponds, at a track radius of 5 cm, to a track portion of approximately 0.2 mm. As should be clear to a person skilled in the art, the number of tilt measurements per disc revolution can suitably be set by setting an appropriate value for the duration  $\tau_{OFF}$  of the normal phase  $T_{OFF}$ . This duration  $\tau_{OFF}$  should preferably be selected

above a certain minimum duration in order to allow the actuator system 50 to obtain a stable position. For the parameters given above, a suitable value for such minimum duration is approximately 1 ms.

5 In figure 3, the basic principle of the present invention is explained by showing that the tilt beam 42 is repeatedly switched ON and OFF, illustrated by a rectangular curve 72 which defines the tilt measuring phase  $T_{ON}$  and the normal phase  $T_{OFF}$ . This curve is not to be interpreted as meaning that the light intensity profile of the tilt beam 42 should have a rectangular shape. On a larger scale than figure 3, figure 4A illustrates a preferred  
10 light intensity profile of the tilt beam 42, indicated by curve 75. The vertical axis of figure 4A indicates light intensity, the horizontal axis indicates time.

At times  $t$  before  $t_1$  and after  $t_2$ , the light intensity  $I(42)$  is zero. At time  $t_1$ , the light intensity  $I(42)$  starts to rise, obtains a maximum at a time  $t_0 = (t_1 + t_2)/2$ , and then decreases continuously to become zero at time  $t_2$ . The shape of curve 75 between times  $t_1$   
15 and  $t_2$  is a cosine shape symmetrical with respect to  $t_0$ .

In order to provide such light intensity profile, the control circuit 90 preferably comprises a shape memory 81, a digital-to-analog converter 82, and a low-pass filter 83, as illustrated in figure 4B. The shape memory 81 contains information on the shape of the light intensity profile to be produced, for instance in the form of a formula or a look-up table.  
20 With such a cosine shape, it is prevented that spectral components in the data frequency range are introduced into the optical detector 35 output signal  $S_R$ .

It should be clear to a person skilled in the art that the present invention is not limited to the exemplary embodiments discussed above, but that various variations and  
25 modifications are possible within the protective scope of the invention as defined in the appending claims.

For instance, in the above it is explained that the signals  $S_D$ ,  $RES$  and  $FES$  are stored in memory and that the control circuit 90 generates, during the tilt measuring phase  $T_{ON}$ , its actuator control signals  $S_{CR}$ ,  $S_{CF}$ ,  $S_{CT}$  on the basis of these stored values in order to  
30 freeze the actuator positions. However, it is also possible that these actuator control signals  $S_{CR}$ ,  $S_{CF}$ ,  $S_{CT}$  themselves are stored in memory, and that the control circuit 90, during the tilt measuring phase  $T_{ON}$ , generates its actuator control signals  $S_{CR}$ ,  $S_{CF}$ ,  $S_{CT}$  by reading the memory and repeating the values read from memory. Further, if the actuators 51, 52, 53 are

relatively slow, and/or if the tilt measuring phase duration  $\tau_{ON}$  is relatively short, it may be that the actuators do not respond to the change in the normalised radial error signal RES illustrated by curve 73, in which case it is not necessary to freeze the actuator control signals. However, freezing the actuator control signals provides an increased robustness of the system.

Further, in the example of a combi-drive as described in the above for explaining a preferred embodiment of the invention, the data beam and the tilt beam have different wavelengths and different amounts of defocus and/or spherical aberration, so that the tilt beam is defocused or spherically aberrated when the data beam is in focus. However, for implementing the present invention, such combination is not necessary. The basic idea behind the present invention is to have two (or more) light beams which have different sensitivity to tilt, such that any disc tilt results in a detectable difference between on the one hand a tilt-induced deflection of the detector spot of the data beam and on the other hand a tilt-induced deflection of the detector spot of the tilt beam. The tilt sensitivity of an optical beam is a property of such optical beam, which may depend on several optical characteristics, such as, for instance, wavelength, focus, spherical aberration, polarization, etc.

In this respect, it is noted that, in any optical disc drive, the objective lens is designed to form, in combination with the material of the optical disc, an optical system which is optimally adapted to a data beam of a certain wavelength (indicated hereinafter as design wavelength), such that, if a light beam having the design wavelength is being used, and if this light beam is substantially parallel (i.e. non-convergent and non-divergent) when entering the objective lens, and if the focus point of this beam coincides with the storage layer of the disc, the reflected beam is substantially free from aberration. This condition will be indicated as the design operation condition, which will be considered as a property of the optical disc drive apparatus. If a second beam is used which does not meet all design operation conditions, the second reflected beam will be subject to some distortion like aberration. As a consequence, in a tilt situation, the detector spot of such second beam, i.e. the light spot caused by such second beam when incident on the detector, is distorted and/or shifted by a different amount than the detector spot of the data beam.

In principle, for being usable in the present invention, it is sufficient if one of the optical characteristics of the tilt beam differs sufficiently from the corresponding optical characteristic of the data beam. So, in one example, the tilt beam has a wavelength differing from the wavelength of the data beam; in such case, the data beam and the tilt beam may be

focussed to the same focus spot on the record layer of the optical disc. In a second example, the focus point of the data beam and the focus point of the tilt beam have different locations on the optical axis, i.e. these focus points have axial distance with respect to each other, such that the tilt beam is out of focus when the data beam is in focus on the record layer of the optical disc; in such case, the data beam and the tilt beam may have the same wavelength. In a third example, the polarization condition of the tilt beam differs from the polarization condition of the data beam, in which case the data beam and the tilt beam may have equal wavelength and equal focus point if the objective lens has refractive properties which are polarization-dependent or if the optical disc has refractive properties which are polarization-dependent, or both.

As mentioned, in a preferred embodiment, the wavelength of the tilt beam differs from the wavelength of the data beam, while also the focal point of the tilt beam is located at an axial distance from the focal point of the tilt beam.

---



## CLAIMS:

1. Method for measuring tilt of an optical disc (2) in an optical disc drive (1), the method comprising the steps of:  
providing a first laser beam (32) for writing/reading the optical disc;  
providing a second laser beam (42) having a tilt sensitivity differing from the tilt sensitivity  
5 of the first laser beam (32);  
directing the two laser beams (32b, 42b) to substantially the same spot (F) on the disc, such that at least the first beam (32b) is substantially focussed on a record layer of the disc;  
receiving reflected light beams (32d, 42d) at an optical detector (35);  
calculating a tilt-indicative signal on the basis of an output signal ( $S_R$ ) from the optical  
10 detector;  
wherein the second light beam (42) is alternately switched ON and OFF.
2. Method according to claim 1, wherein the second beam (42) has at least one  
optical characteristic differing from the corresponding optical characteristic of the first beam  
15 (32).
3. Method according to claim 1, wherein the first laser beam has a first colour  
and wherein the second laser beam has a second colour differing from the first colour.
- 20 4. Method according to claim 3, wherein the second laser beam has a focus point  
substantially coinciding with a focus point of the first laser beam.
5. Method according to claim 1, wherein the first laser beam has a first focus  
point and wherein the second laser beam has a second focus point located at an axial distance  
25 from the first focus point.
6. Method according to claim 5, wherein the first laser beam and the second laser  
beam have substantially the same colour.

7. Method according to claim 1,

wherein the first laser beam has a first colour and wherein the second laser beam has a second colour differing from the first colour; and

wherein the first laser beam has a first focus point and wherein the second laser beam has a

5 second focus point located at an axial distance from the first focus point.

8. Method according to claim 1, wherein a tilt-indicative signal is derived by comparing, on the one hand, at least one measuring signal obtained during a tilt measuring

phase ( $T_{ON}$ ) when the second light beam (42) is switched ON with, on the other hand, at least

10 one measuring signal obtained during a normal phase ( $T_{OFF}$ ) when the second light beam (42) is kept switched OFF.

9. Method according to claim 8, wherein, in the tilt measuring phase ( $T_{ON}$ ), the

intensity of the second light beam (42) is caused to continuously rise from zero to a

15 maximum value at approximately half-time ( $t_0$ ) in the tilt measuring phase ( $T_{ON}$ ), and

subsequently caused to continuously decrease from said maximum value to zero.

10. Method according to claim 9, wherein a light intensity profile of the second light beam (42) substantially has a cosine shape.

20

11. Method according to claim 8, wherein the said measuring signal is the normalized radial error signal (RES).

12. Method according to claim 8, wherein a first measuring signal (RES(OFF)) is

25 obtained shortly before the start ( $t_1$ ) of a tilt measuring phase ( $T_{ON}$ );

wherein a second measuring signal (RES(ON)) is obtained within the tilt measuring phase ( $T_{ON}$ );

and wherein the tilt-indicative signal is derived by comparing the first measuring signal (RES(OFF)) with the second measuring signal (RES(ON)).

30

13. Method according to claim 8, wherein a first measuring signal (RES'(OFF)) is

obtained shortly after the end ( $t_2$ ) of a tilt measuring phase ( $T_{ON}$ );

wherein a second measuring signal (RES(ON)) is obtained within the tilt measuring phase

(T<sub>ON</sub>);

and wherein the tilt-indicative signal is derived by comparing the first measuring signal (RES'(OFF)) with the second measuring signal (RES(ON)).

- 5 14. Method according to claim 8, wherein a first measuring signal (RES(OFF)) is obtained shortly before the start (t<sub>1</sub>) of a tilt measuring phase (T<sub>ON</sub>); wherein a second measuring signal (RES(ON)) is obtained within the tilt measuring phase (T<sub>ON</sub>); wherein a third measuring signal (RES'(OFF)) is obtained shortly after the end (t<sub>2</sub>) of a tilt  
10 measuring phase (T<sub>ON</sub>); and wherein the tilt-indicative signal is derived by comparing the second measuring signal (RES(ON)) with a combination of the first measuring signal (RES(OFF)) and the third measuring signal (RES'(OFF)).
- 15 15. Method according to claim 12, 13, or 14, wherein the second measuring signal (RES(ON)) is obtained from a measurement result substantially obtained at a central time (t<sub>0</sub>) within the tilt measuring phase (T<sub>ON</sub>).
16. Method according to claim 12, 13, or 14, wherein the second measuring signal  
20 (RES(ON)) is obtained from combining a plurality of measurement results obtained within the tilt measuring phase (T<sub>ON</sub>).
17. Method according to claim 1, wherein at least one control signal (S<sub>CR</sub>) for at least one lens actuator (51) is frozen during a tilt measuring phase (T<sub>ON</sub>) when the second  
25 light beam (42) is switched ON.
18. Method according to claim 17, wherein the value of at least one optical detector (35) output signal shortly before the start (t<sub>1</sub>) of a tilt measuring phase (T<sub>ON</sub>) is stored in a memory (97);  
30 wherein, during said tilt measuring phase (T<sub>ON</sub>), said memory (97) is read for retrieving said value; and wherein, during said tilt measuring phase (T<sub>ON</sub>), said at least one control signal (S<sub>CR</sub>) for

said at least one lens actuator (51) is generated on the basis of said value read from memory (97).

19. Method according to claim 17, wherein the value of said at least one control  
5 signal ( $S_{CR}$ ) shortly before the start ( $t_1$ ) of a tilt measuring phase ( $T_{ON}$ ) is stored in a memory (97);  
wherein, during said tilt measuring phase ( $T_{ON}$ ), said memory (97) is read for retrieving said value;  
and wherein, during said tilt measuring phase ( $T_{ON}$ ), said at least one control signal ( $S_{CR}$ ) for  
10 said at least one lens actuator (51) is generated on the basis of said value read from memory (97).

- 
20. Optical disc drive (1) for writing/reading information into/from an optical  
storage disc (2), comprising:  
15 light generating means (31; 41) for generating a first laser beam (32) and a second laser beam (42) having a tilt sensitivity differing from the tilt sensitivity of the first laser beam (32);  
an objective lens (34);  
an actuator system (50) for positioning the objective lens (34);  
an optical detector (35) for receiving light (32d, 42d) reflected from disc;  
20 a control circuit (90) for controlling the actuator system (50) on the basis of an output signal ( $S_R$ ) from the optical detector;  
wherein the control circuit (90) is adapted to generate a control signal ( $S_{L2}$ ) for said light generating means (31; 41) such as to alternately switch ON and OFF the second light beam (42).

25

21. Optical disc drive (1) according to claim 20, wherein said light generating means (31; 41) comprise a first light generating device (31) for generating said first laser beam (32) and a second light generating device (41) for generating said second laser beam;  
and wherein the control circuit (90) is adapted to generate said control signal ( $S_{L2}$ ) to  
30 alternately switch ON and OFF the second light generating device (41).

22. Optical disc drive (1) according to claim 20, wherein said first laser beam (32) has a first colour and wherein the second laser beam (42) has a second colour differing from the first colour.

5 23. Optical disc drive (1) according to claim 20, wherein said first laser beam has a first focus point and wherein said second laser beam has a second focus point located at an axial distance from the first focus point.

10 24. Optical disc drive (1) according to claim 20,  
wherein said first laser beam (32) has a first colour and wherein the second laser beam (42) has a second colour differing from the first colour; and  
wherein said first laser beam has a first focus point and wherein said second laser beam has a second focus point located at an axial distance from the first focus point.

15 25. Optical disc drive according to claim 20, adapted to perform the method according to any of claims 1-19.

20 26. Optical disc drive according to claim 21, adapted to handle one disc type (for example CD or DVD or Blu-Ray) only, wherein the second light generating device (41) is an auxiliary light source.

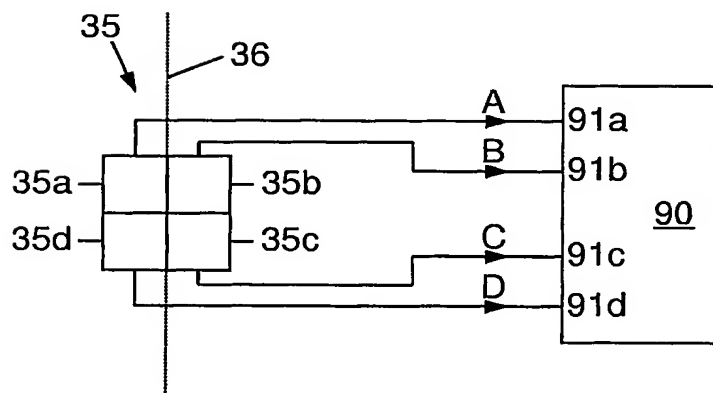
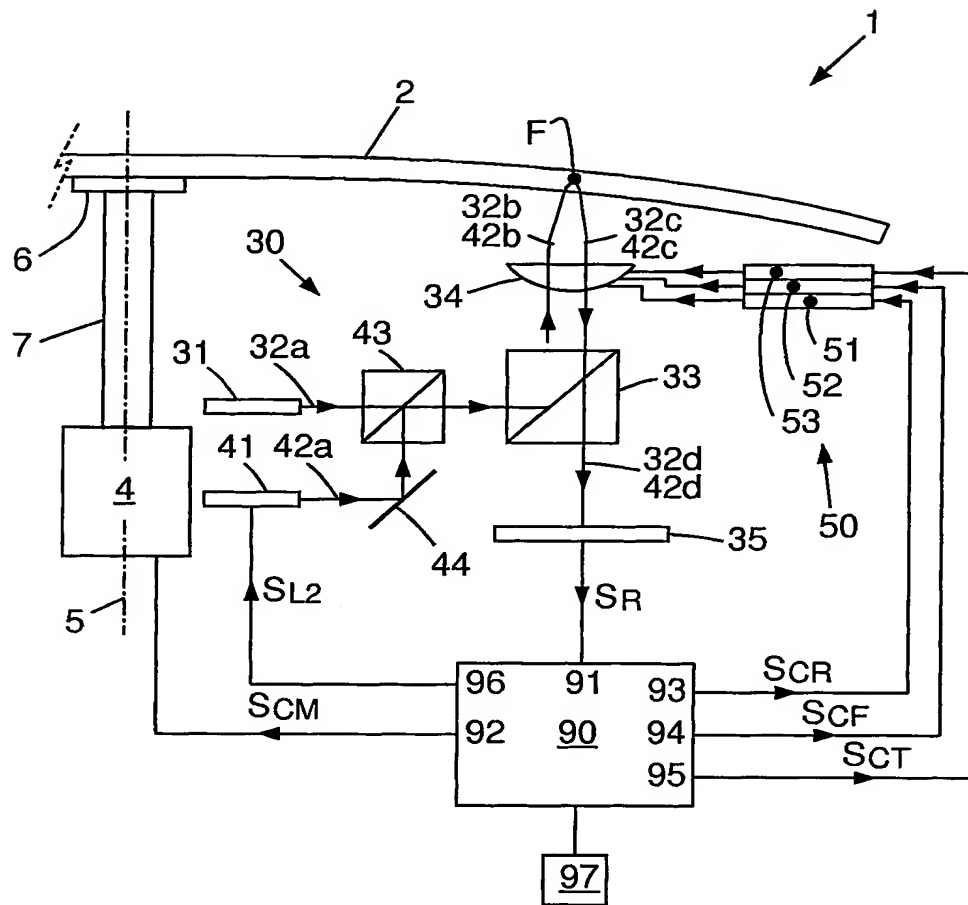
25 27. Optical disc drive according to claim 21, adapted to handle at least two different disc types (for example: CD, DVD, Blu-Ray), wherein the first light generating device (31) is adapted to generate the first light beam (32) suitable for handling a first one of said disc types and wherein the second light generating device (41) is adapted to generate the second light beam (42) suitable for handling a second one of said disc types.

**ABSTRACT:**

A method for measuring tilt in an optical disc drive (1) is disclosed. The optical disc drive (1) comprises two lasers (31, 41) generating two laser beams (32, 42) having mutually different colours. One of these laser beams (32) is continuously ON, and is used for writing or reading data to or from the disc. The other laser beam (42) is repeatedly  
5 switched ON and OFF. During the ON-phase ( $T_{ON}$ ), actuators (51, 52, 53) are frozen. Tilt is measured by comparing the normalized radial error signal ( $RES(ON)$ ) during the ON-phase ( $T_{ON}$ ) with the normalized radial error signal ( $RES(OFF)$ ) during the OFF-phase.

Figure 3

1/3



2/3

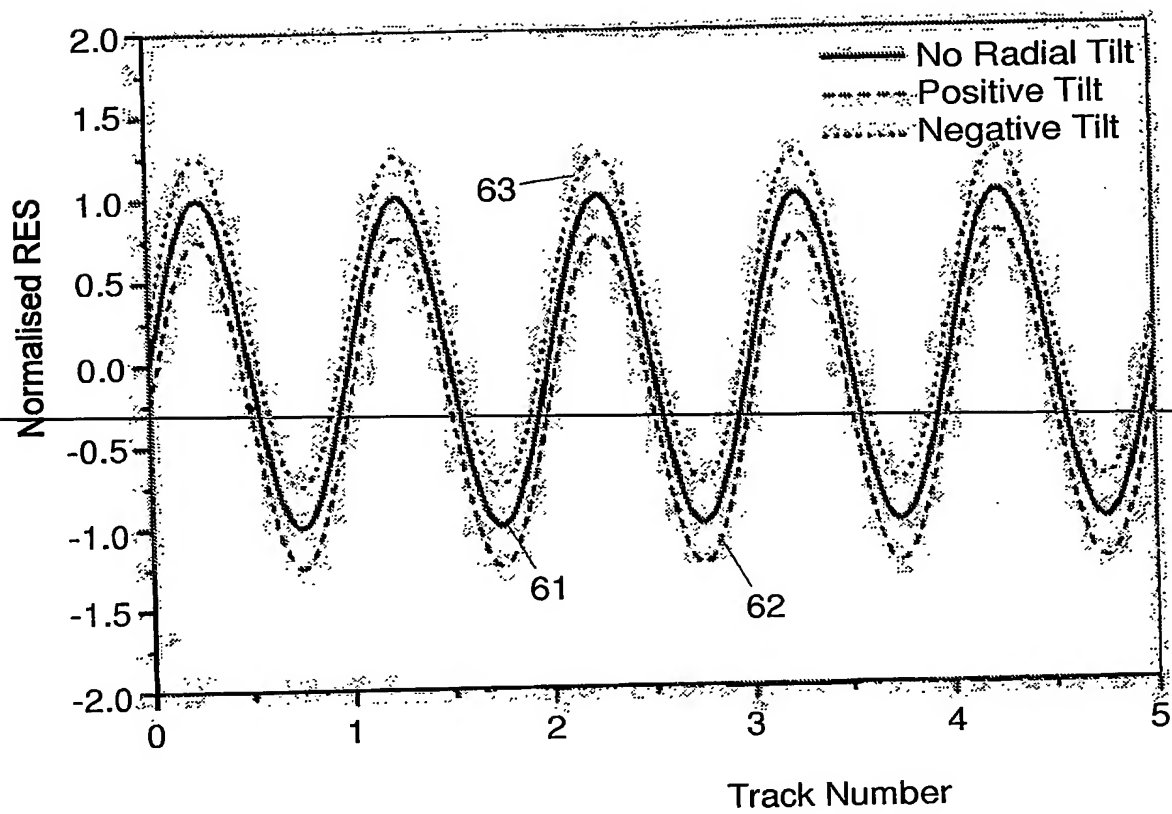


FIG.2



3/3

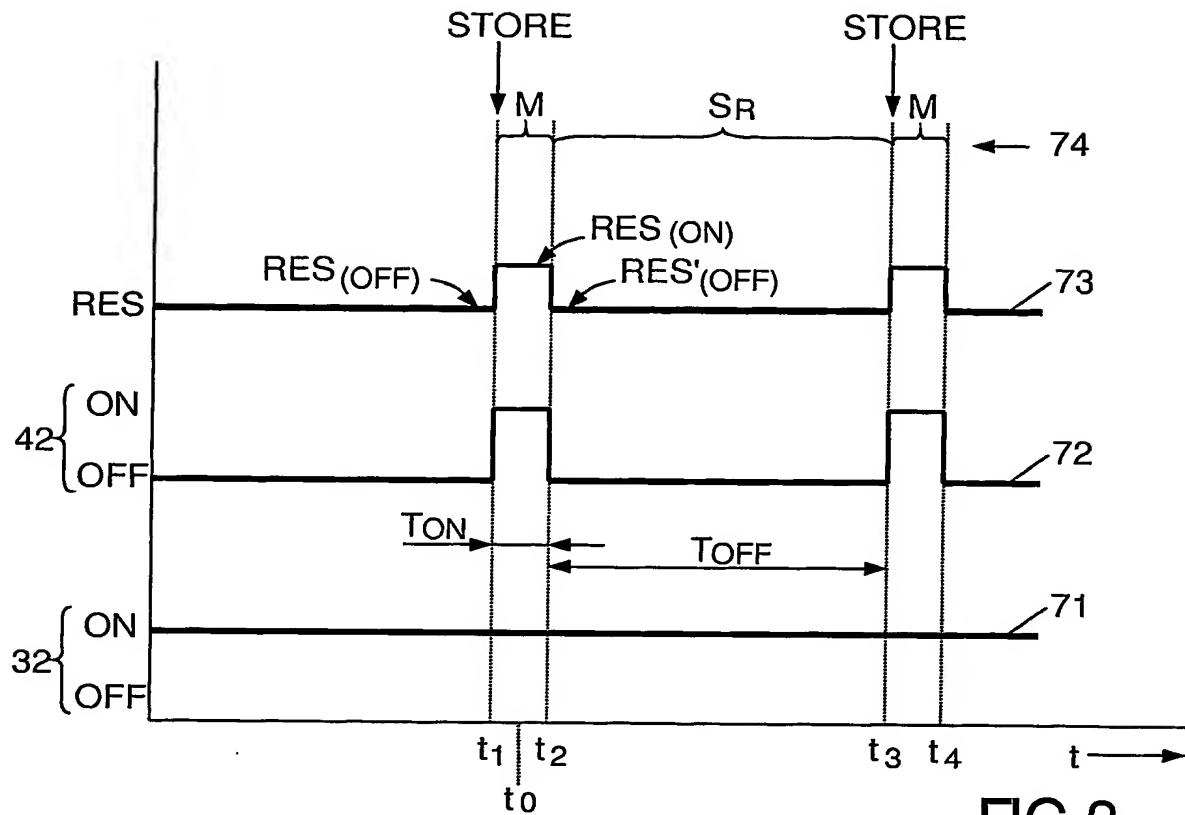


FIG.3

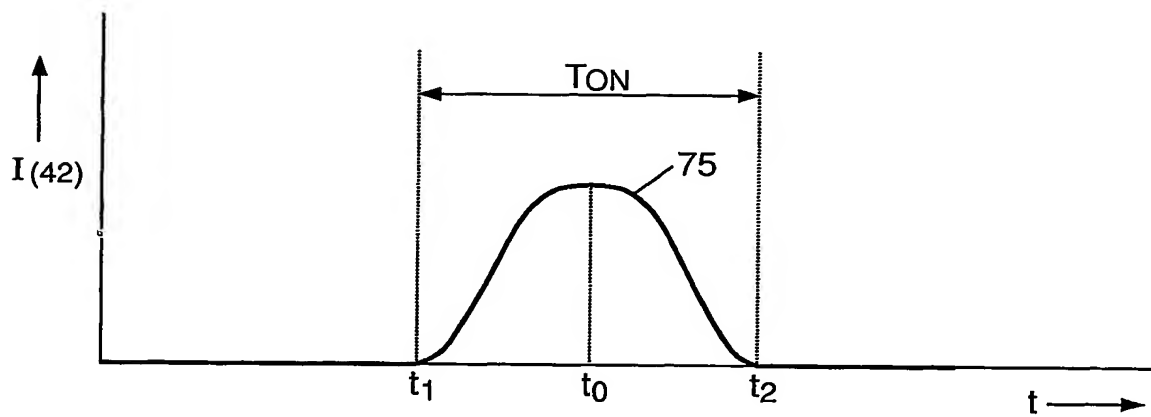


FIG.4A

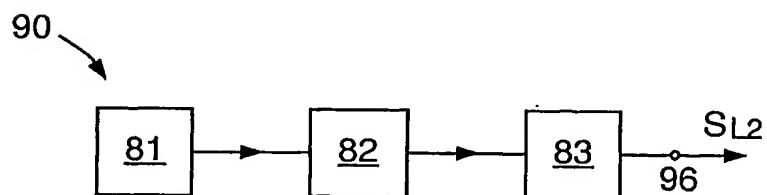
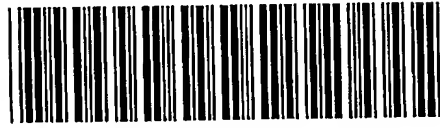


FIG.4B

**PCT/IB2004/000831**



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